ron.

BULLETIN

OF

The Terrestrial Electric Observatory

OF

FERNANDO SANFORD
Palo Alto, California

VOLUME IV

Summary of Observations on Earth-Potential
and Air-Potential Gradients for the year 1926,
with some Theoretical Considerations

Palo Alto, California
March 1927

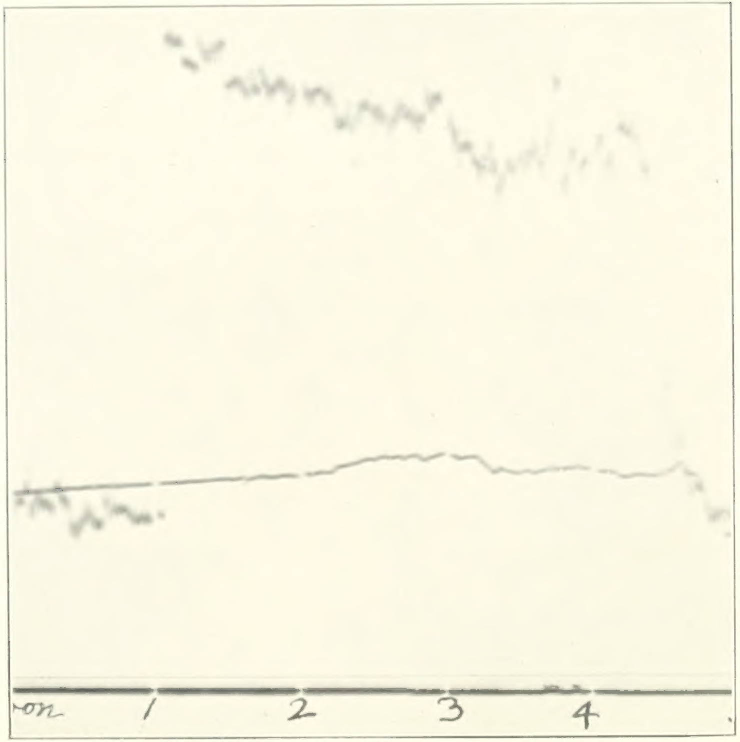

FIGURE 2

Reproduction of record of electrometer deflection due to sudden variation in earth potential.

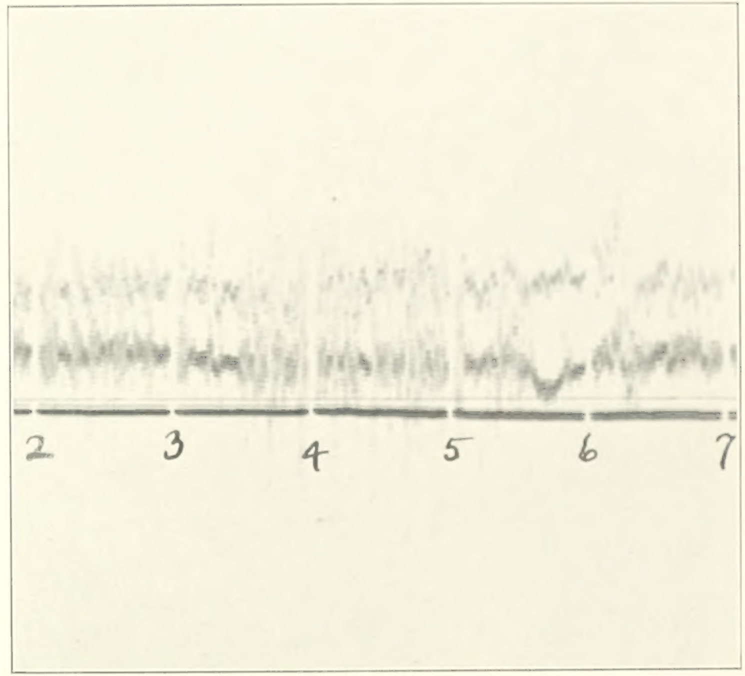

FIGURE 5

Reproduction of two electrometer records during a period of unsteadiness. The upper record is due to the air-potential electrometer and the record nearer the base line to the earth-potential electrometer.

BULLETIN

OF

The Terrestrial Electric Observatory

OF

FERNANDO SANFORD
Palo Alto, California

VOLUME IV

Summary of Observations on Earth-Potential and Air-Potential Gradients for the year 1926, with some Theoretical Considerations

Palo Alto, California
March 1927

STANFORD UNIVERSITY

PRESS

CONTENTS

SUMMARY OF OBSERVATIONS ON EARTH-POTENTIAL AND AIR-POTENTIAL GRADIENTS FOR THE YEAR 1926, WITH SOME THEORETICAL CONSIDERATIONS

Observations on Earth-Potential and Air-Potential Variations

General outline of work for the year.—During the year 1926 observations on the diurnal variation of earth potential and air potential were carried on at this observatory. On account of the serious disturbances due to ground currents from trolley lines, the work of previous years on earth-current variations was discontinued. No records were made during the month of May. No air-potential records were made in February, and no earth-potential records in April. During the year the variation in earth-potential was recorded on 244 days and air-potential records were obtained for 225 days.

The method of making these records has been described in previous numbers of this *Bulletin*. Briefly, two quadrant electrometers were used. Both stood on the same wooden pier inside a cage of wire netting which was four feet square at its base and eight feet high. The electrometer used for measuring variations of earth potential had one pair of quadrants earthed through the case of the instrument, the wire cage, and the water system of Palo Alto. The other pair of quadrants was connected by an insulated wire to an insulated metal conductor which was inside a thermos bottle, a metal case, and a porcelain jar. The variation in potential difference between the two pairs of quadrants has been attributed to a variation in the electrical potential of the ground at this place. Reasons why this change has been attributed to the earth rather than to the insulated conductor have been given in previous volumes, especially in Volume II.

The air-potential electrometer had its two pairs of quadrants connected to two copper balls, one seven inches and the other eight inches in diameter, which were suspended above the roof of the observatory. One of these balls was three meters above the other, which was only one meter above the roof. Both balls were enameled to insure high insulation, and both were suspended by flint glass insulators inside of bottles from which the bottoms had been removed. This was to shield them from rain and dust. The wires leading to the electrometer were heavy, rubber-insulated wires which were also shellacked. It seems improbable that the balls or conducting wires could have taken rapidly changing charges from the air.

On account of the fact that the observatory is surrounded by trees, several of which are taller than the mast by which the balls are supported, both balls are in a very weak electric field, and the potential difference

between them does not average more than a few tenths of a volt. The potential variation between them is often greater than their total potential difference at times of no disturbance.

Both electrometer needles were charged by separate dry batteries inside the cage. These batteries were shielded by earthed metal screens, and one pole of each battery was earthed. A diagram of the arrangement is shown in Figure 8 of Volume III. The only difference in the present arrangement from that used in 1925 is in the insulation of the surface of the balls, which in 1925 was bare.

Diurnal earth-potential variation for 1926.—During the year 1926 the diurnal variation of earth potential at Palo Alto was photographically recorded for 244 days. The records were corrected for temperature deflections due to the rotation of the electrometer-needle suspension, as was shown to be necessary in Volume III of this *Bulletin.*

There were a number of days during which the range of variation was much greater than usual, but all days for which the records were complete were used in calculating the mean diurnal variation for the year. This mean diurnal variation in millivolts is given in Table I and is shown graphically in Curve *A* in Figure 1.

TABLE I

Mean Diurnal Variation in Millivolts of Earth Potential for 1926

Hour	1	2	3	4	5	6	7	8	9	10	11	Noon
A.M.	+ 240	+ 250	+ 260	+ 300	+ 330	+ 350	+ 350	+ 300	+ 190	− 100	− 270	− 310
Hour	1	2	3	4	5	6	7	8	9	10	11	12
P.M.	− 290	− 310	− 300	− 240	− 190	− 220	− 140	− 90	+ 5	+ 60	+ 130	+ 190

Disturbances of earth potential.—In Volume III attention was called to a certain disturbance of earth potential which usually began with a sudden negative deflection of the electrometer needle. Figure 2 (see frontispiece) is a reproduction, natural size, of the record made by such a disturbance on March 19, 1926. As may be seen from the record, it began about 1:05 P.M., and the first deflection was too rapid to be recorded on the photographic paper. This deflection indicated a change of potential of about —.65 volt.

Similar disturbances have occurred even more frequently during the past year than during 1925. Six of these disturbances indicated a potential change of more than half a volt each. Usually the larger disturbances came in groups or series lasting for several days. In this event there were usually recurrent disturbances of similar character beginning at approximately the same hour on succeeding days.

Probably the most interesting series of disturbances of the year occurred from January 16 to 26. The records of January 16 and 17 went off the sheet and could not be measured, but the records of January 18–22 are shown in Figure 3, where they are compared on the same scale with the

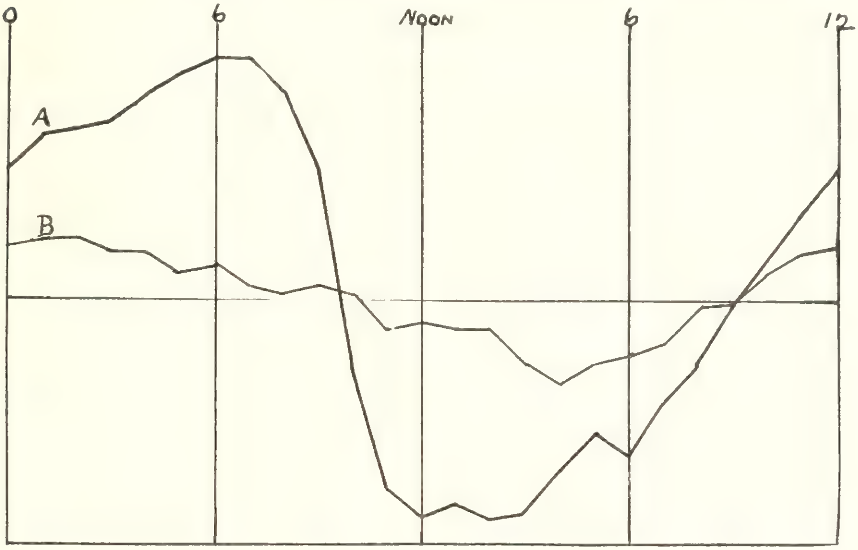

FIGURE 1

Curve A represents the mean-diurnal variation of earth potential at Palo Alto for 244 days in 1926. Curve B represents the mean lunar diurnal variation for 216 days of the same period.

mean curve of diurnal variation for 244 days, which is shown at the top of the series. The hump due to this disturbance was still visible on the record of January 26.

The fact that this disturbance began at the same hour on successive days shows that it was related to the position of the sun, and not to any local cause. The Mount Wilson summary of magnetic observations of sun-spots says: "The most remarkable groups observed during January and February were Nos. 2447 and 2453." Both of these, as well as a number of other considerable groups, were visible during the time covered by the disturbance shown in Figure 3. Whether the sun-spot activity was the cause of the disturbance, or not, the fact of its successive reappearances at a particular hour-angle of the sun is strong evidence that it traveled around the earth with the sun, and hence was due to some solar phenomenon.

Of the 244 days for which measureable records were obtained, there were 59 days when the range of electrometer deflection indicated a potential

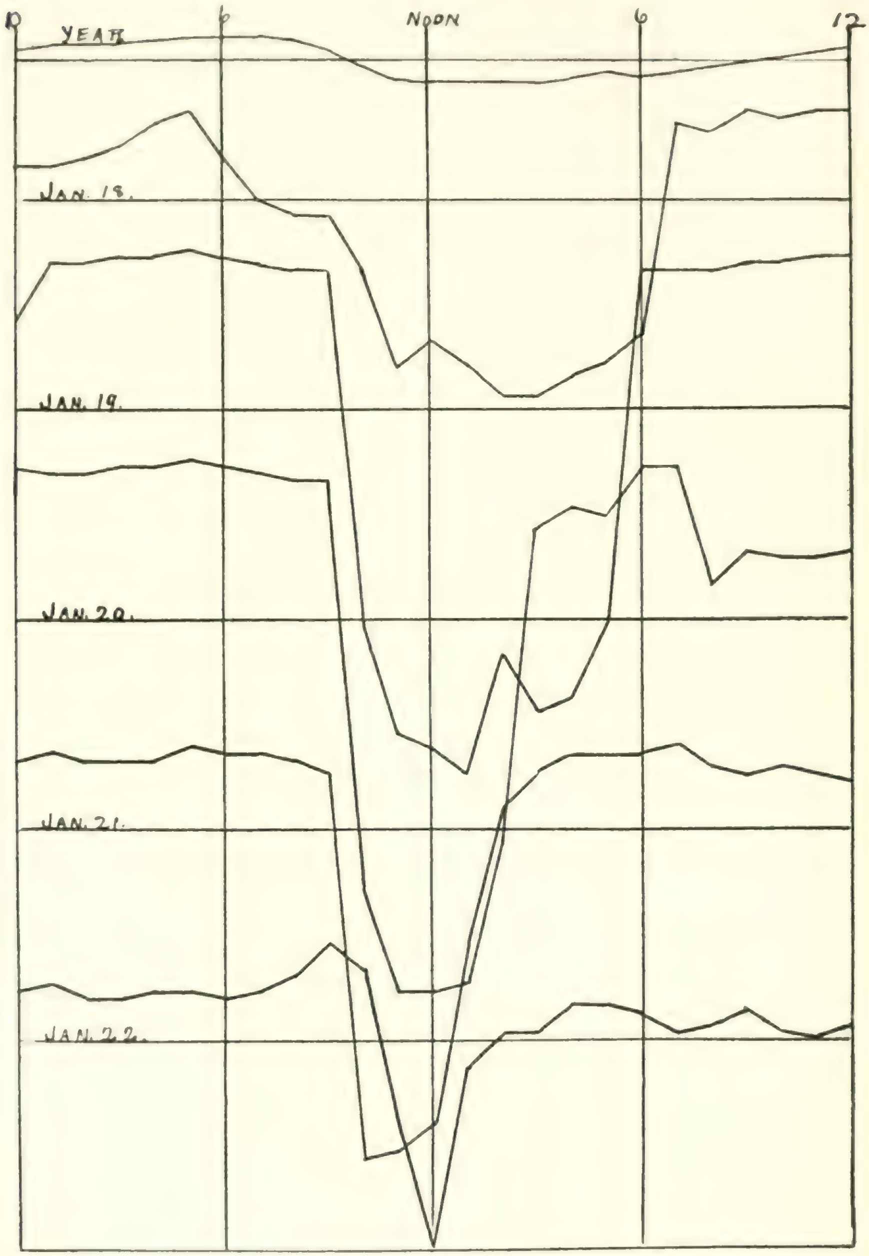

FIGURE 3

Curves showing the relative variations in earth potential on the days indicated as compared with the mean variation for 244 days, as shown at top of page.

change of one one-fifth volt, or more. In Figure 4 the mean daily range for these 59 days is compared with the mean daily range for the other 185 days. The dotted curve represents the mean diurnal variation for the 59 days of greatest range. It will be seen that the greater range of variation on these days is principally due to an increase in the negative potential of the earth, which in the records gave a deflection toward the top, but is plotted toward the bottom in all the curves. It will also be seen that this negative deflection began between 9:00 A.M. and noon in a great majority of the cases.

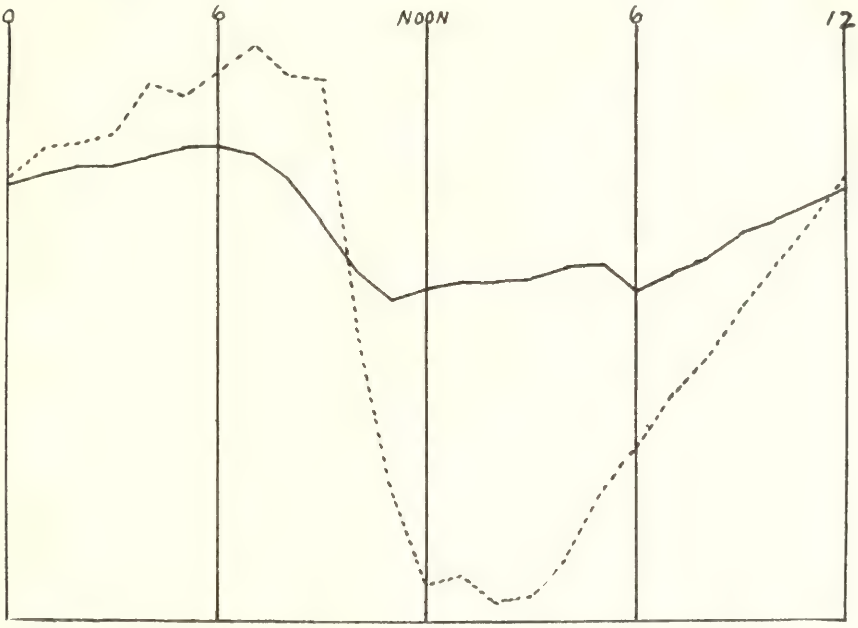

FIGURE 4

The mean daily range of earth potential for 59 days of large variation, as shown by the dashed curve, and for 185 days of smaller range, shown by the continuous curve.

Lunar diurnal variations of earth potential.—The diurnal variation of earth potential for 216 lunar days in 1926 was determined by subtracting from the hourly electrometer deflections for each day of the month the mean value of the deflection at that same hour of the day for all the days of the month for which records were available, and arranging the residuals according to their respective lunar hours, taking the hour nearest the moon's upper culmination as the mid-hour of the lunar day. The mean variation of the 216 lunar days obtained in this way was then determined.

This mean variation in millivolts is given in Table II, and is shown graphically in Curve *B* of Figure 1, where it may be compared with the curve of solar variation.

TABLE II

Mean Lunar Diurnal Variation of Earth Potential for 216 Days in 1926

Hour	1	2	3	4	5	6	7	8	9	10	11	U.O.
A.M.	+90	+90	+70	+ 70	+40	+50	+20	+10	+20	+10	−40	−30
Hour	13	14	15	16	17	18	19	20	21	22	23	24
P.M.	−40	−40	−90	−120	−90	−80	−60	−10	+ 5	+40	+70	+80

The lunar diurnal variation as determined above contains not only the variations due to the moon's induction, but all the disturbances, of whatever kind, which cause the electrometer deflections for a given day to vary from its mean deflection for the month. It is too much to expect that these irregular deflections will all cancel each other unless a very large number of days is used. Nevertheless, the curve given in Figure 1 shows conclusively that a lunar deflection of the same general character as the solar deflection does actually occur.

Diurnal air-potential variations.—The difference in the apparatus used in recording the air-potential variations in 1925 and in 1926 consisted in enameling the copper balls between which the potential difference was measured, and in more careful insulation of the conducting wires from the free charges in the atmosphere. Instead of using the copper balls as collectors of atmospheric charges, the attempt was made to prevent them, as far as possible, from collecting any charges whatever. Thus they represented merely extensions of the electrometer quadrants into a very weak electrical field about the earth, one of them extending three meters farther than the other into this field.

Under these conditions any sudden change in the potential difference between the balls must be due to induction from a charge on some outside body, and this charge must be nearer to one ball than to the other, and must rapidly change either its distance or its magnitude or distribution.

The diurnal variation in potential difference between the balls arranged in this way was greater than has been observed in previous years; but whether this was due to the more perfect insulation of the balls and wires or to external conditions I am unable to say. The diurnal variations in earth potential were also greater than in previous years except at times of great disturbance. Irregularities in the earth-potential and air-potential curves seemed sometimes to be due to the same external cause, and some-

times to be due to different causes. Thus, great changes in the potential difference between the balls often occurred at times of showers of rain, which seemed to produce little or no change in the potential difference between the earth and the insulated capacity attached to the earthed electrometer. This disturbance could not well be attributed to electrified rain drops, because both balls were exposed alike to the rain, but must have been due to rapid variations of the space charges in the atmosphere.

Sometimes both the air-potential and the earth-potential electrometers were restless for hours, or even days, at a time. A moderate example of this restlessness is shown in the record reproduced in Figure 5 (see frontispiece), which covers a period from 2:00 o'clock to 7:00 o'clock on the afternoon of October 7. The upper record is due to the air-potential electrometer and the one nearer the base line to the earth-potential electrometer. In this particular case both electrometers were unsteady most of the time for five days, which period was followed by a considerable rain storm.

On the other hand, it will be seen by referring to Figure 2 that at the beginning of the great earth-potential disturbance there recorded, the air-potential record (shown by the line above the base line) was not at all disturbed, and showed no great unsteadiness, though a considerable deflection, at the end of the earth-potential deflection. The same was true during the remainder of that day and the day following, though there were a number of considerable slow deflections of the air-potential electrometer.

The mean diurnal variation of the potential difference in millivolts between the two copper balls for 225 days is given in Table III and is shown graphically in the continuous curve of Figure 6.

TABLE III

Mean Variation of Air-Potential Gradient for 225 Days. The + Sign Indicates an Increase in the Positive Potential of the Upper Ball

Hour	1	2	3	4	5	6	7	8	9	10	11	Noon
A.M.	−36	−63	−72	−54	−54	−33	+ 3	+24	+21	−30	− 6	+42
Hour	1	2	3	4	5	6	7	8	9	10	11	12
P.M.	+36	+51	+54	+39	+21	+18	+12	+15	0	−21	−18	−30

The character of the curve given by the foregoing data seems to indicate that there was a sudden negative change of the air potential at the same hour as the negative deflection in the earth-potential disturbances, but this may be accidental. The monthly air-potential curves were generally quite different from one another, but may be roughly summarized under

three general types. The months January, March, November, and December gave curves with a marked minimum at 10:00 A.M. (as shown in the curve for the whole period), and a principal maximum at 2:00 P.M. with a smaller maximum at 7:00 A.M. June and July gave curves with a single high maximum at 10:00 A.M. and a low minimum at 2:00 to 5:00 A.M. August and September gave the summer form of air-potential curve which is most common at stations in the Northern Hemisphere. This curve is shown by the dotted line in Figure 6.

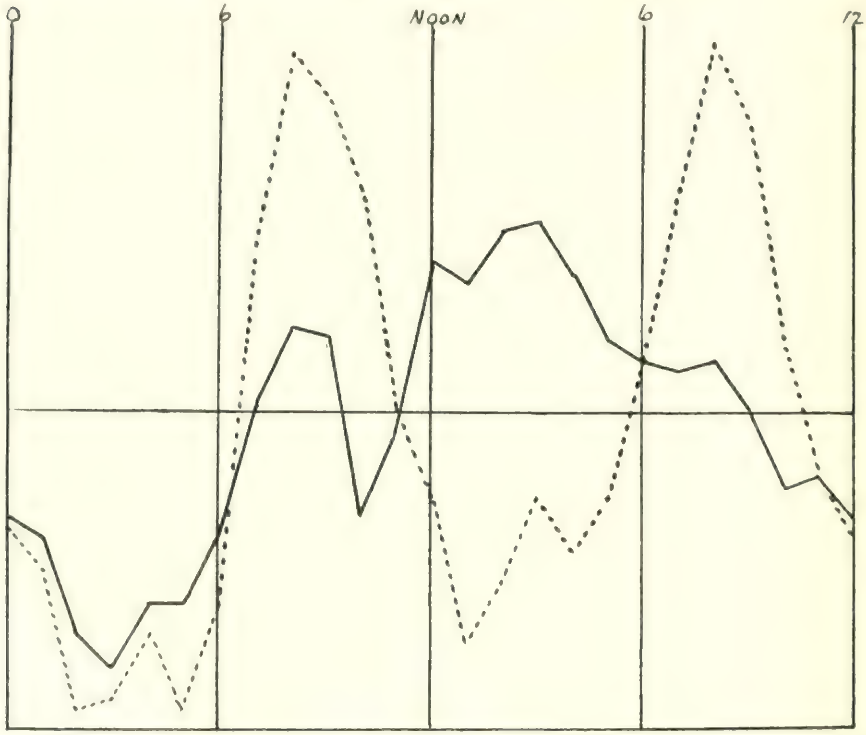

FIGURE 6

The continuous curve shows the mean diurnal variation of potential difference between two insulated copper balls suspended, one above the other, in the free air for 255 days. The dotted curve shows the mean variation of the same difference for the months of August and September.

Lunar diurnal variation of air potential.—That the moon exerts an appreciable effect upon the diurnal variation of air potential was first definitely shown in Volume II of this *Bulletin.* The diurnal variation of air potential for 214 lunar days of 1926 was determined in two ways: first, in the same manner that the lunar variation in earth potential was

shown, and second, by taking for each hour the number of times when the occurrence of the + or — sign in the record exceeded 107 times in the 214 days. The results of the determinations are shown in Tables IV and V, and the two curves are given in Figure 7.

TABLE IV

Lunar Diurnal Variation of Air-Potential Gradient for 214 Days

Hour	1	2	3	4	5	6	7	8	9	10	11	U.C.
A.M.	−27	−28	− 7	+ 7	+ 3	+ 2	+ 9	+20	+13	+21	+28	+25
Hour	13	14	15	16	17	18	19	20	21	22	23	24
P M.	+10	+ 2	− 2	+ 2	+ 2	+ 6	+12	+ 1	−11	−17	−27	−18

TABLE V

Number of Times When the + or — Sign Occurred in Excess of 107 Times in 214 Days

Hour	1	2	3	4	5	6	7	8	9	10	11	U.C.
A.M.	−24	−23	−15	−11	−15	−24	−10	+ 6	+ 3	− 7	+ 5	+ 6
Hour	13	14	15	16	17	18	19	20	21	22	23	24
P.M.	− 4	−12	− 5	−10	− 7	−10	− 2	−10	−27	−25	−39	−34

The two curves for lunar diurnal variation are shown in Figure 7, in which the continuous line represents Table IV and the dashed line Table V.

When the two curves are combined, giving them equal value, the continuous curve in Figure 8 results. The dashed curve in the same figure is the resultant formed in the same manner from the two corresponding curves for 1923–24, as shown in Volume II.

Some Conditions Which Must Exist in a Highly Electrified Solar System

The phenomena which have been described in this and the preceding volumes published from this observatory seem to be incapable of any other interpretation than that of an enormous negative charge on the sun and other members of the solar system. Seemingly, the only way to escape this conclusion is to doubt the accuracy of the observations, and they are of such a simple character that they may be tested in any physical laboratory.

Accordingly, it seems suitable at this stage of the investigation to call attention to some of the logical deductions which may be drawn from this premise, and to inquire if they correspond to known phenomena or to phenomena which are capable of observation.

Planetary perturbations.—In his argument against Ayrton and Perry's

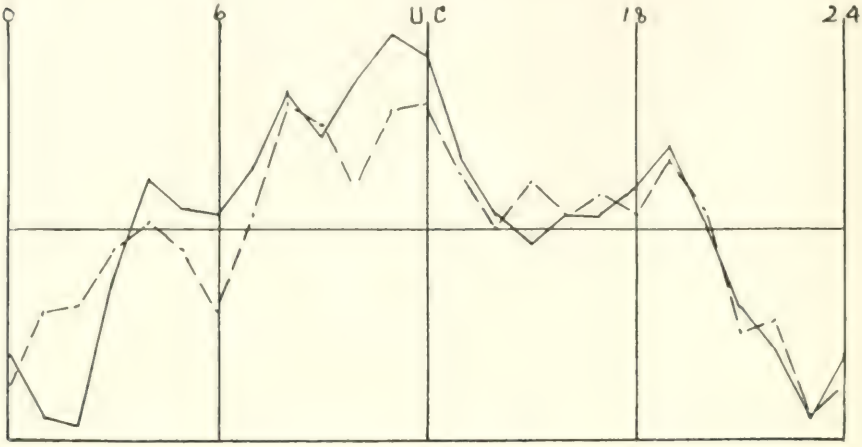

FIGURE 7

Diurnal variation of air potential for 214 lunar days, as shown by the data in Table IV and Table V.

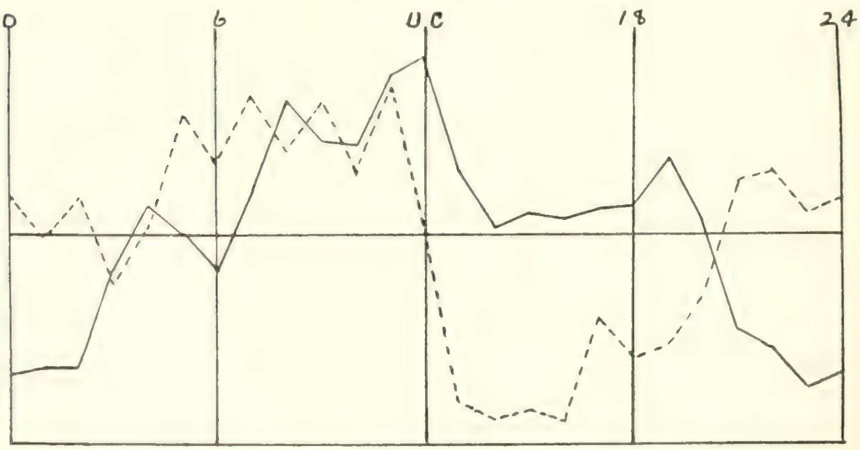

FIGURE 8

Lunar diurnal variation of air-potential gradient for the year 1926 (continuous curve) and for 1923–24 (dashed curve).

theory of the earth's magnetism, viz., that the earth's magnetic field is produced by the rotation of its negative charge, Rowland says:*

> If the moon were electrified to a like potential the force of repulsion would be greater than the gravitation attraction of the earth, and it would fly off through space.

This opinion, or one similar to it, seems to be held by many other physicists, but a little consideration will show that it is without justification. It is true that if the sun and other bodies of the solar system carry the enormous charges which their magnetic fields and other phenomena seem to require they will repel one another with very great forces, which will approximately follow the inverse square law; but these forces are already involved in what we call gravitation. Nobody knows anything about gravitation *per se*. What we know as gravitation is the resultant of whatever forces, attractive and repulsive, exist between the bodies of the solar system. Gravitation has never been analyzed. If it be made up of few or many component forces, so long as they all follow the inverse square law of attraction or repulsion between the centers of mass of the gravitating bodies they cannot be separately distinguished. If electrical repulsion be one of these constituent forces, since it does not act between the centers of mass of charged bodies, it is not impossible that it may be detected and evaluated.

Electrical repulsion follows the inverse square law between point charges and between charges on physical bodies at distances so great that the bodies may be regarded as points; but it does not even approximately follow the inverse square law between charges on extended bodies when near together. Thus, we may have two bodies similarly charged, either both positive or both negative, which will repel each other at one distance and attract each other at another distance.

If two similarly electrified spheres approach each other, when they are near together their repulsion does not increase as rapidly as it should from the inverse square law. Let us suppose, for example, a negatively electrified sphere to be revolving around another negatively electrified sphere in an elliptical orbit of considerable eccentricity under the influence of gravitation, as would be the case with Mercury and the sun if both were negatively electrified. Then, while the other components of gravitation follow the inverse square law, the electrical component does not, and the resultant attraction between the two bodies will increase faster than the inverse square law would predict as they approach each other and will fall off slower as they recede from each other. Accordingly, if Mercury and the sun carry great negative charges, Mercury's speed must increase as it

* Rowland, *Collected Papers*, p. 179.

approaches perihelion as if there were an additional force added to gravitation. The same should be true of our moon as it approaches perigee.

It is well known that there are perturbations in the orbits of Mercury and the moon under these circumstances which cannot be accounted for on the assumption of an inverse square force of attraction between them and the sun or the earth. Lecornu and Haag* maintain that the irregularities in the perihelion motion of Mercury may be explained by a force added to the Newtonian gravitation, which force is perpendicular to the velocity of the planet and is proportional to the inverse third power of the distance. Such a force approximates closely to what would result if there were an electrical repulsion between the two bodies.

None of the planets of our system except Mercury have sufficiently eccentric orbits to make such an effect appreciable, but such an effect might well be appreciable in the orbit of our moon, which also shows perturbations not hitherto explained.

Influence of planetary charges in the formation of sun-spots.—This subject has been discussed in a paper entitled "On the Origin of Sun-Spot Vortices" in *Science* of January 14, 1927. In this paper it is shown that there is conclusive evidence that sun-spot formation is influenced by planetary configurations, and that the planetary influence is not of the nature of gravitational tides on the sun, which tides are of the same character on the side toward and the side opposite the tide-producing body. In the case of the combined action of two planets in producing gravitational tides the tides would be at a maximum at times of both planetary conjunction and opposition, while in the case of electrostatic tides they would be at a maximum at times of planetary conjunction and at a minimum at times of planetary opposition. The data which have been gathered on the influence of planetary configuration on the formation of sun-spots show that two planets have their greatest spot-producing effect when they are in conjunction and their least effect when they are in opposition.

The effect of the repulsion of a planetary charge upon the electrified solar atmosphere is to cause ascending currents in this atmosphere on the side of the sun opposite to the planet and descending currents on the side toward the planet. These regions then correspond respectively to regions of low and of high barometric pressure in the earth's atmosphere.

Sun-spots are known to be the visible manifestations of great cyclonic storms in the electrified solar atmosphere. Such storms should be set up by the electrified winds blowing from all directions toward the regions of ascending currents, just as cyclones are formed upon the earth. Hence an electrified planet should assist in the formation of sun-spots on the side

* *Comptes Rendus,* 176, 163 and 204–5 (1923).

of the sun turned from it, and in suppressing sun-spots on the side of the sun facing it. This explains Mrs. Maunder's observations on the influence of the earth in suppressing sun-spots on the visible hemisphere of the sun, as published in *Monthly Notices of the Royal Astronomical Society* of May, 1907, and Evershed's observation on the repulsion of the gases of the sun by the earth as published in *Observatory,* London, **42,** 51–2 (1919).

A possible change of distribution of the solar charge.—There is an important difference in the average diurnal range of magnetic variation in years of many and of few sun-spots. Attention is called to this in Chree's *Studies in Terrestrial Magnetism,* p. 161, and it is plainly shown in the records of the Observatorio del Ebro. In years of great sun-spot frequency the average daily range of magnetic variation is greater in all the magnetic elements than in years of few sun-spots. In Chree's data from years where the average sun-spot frequency was 75 and years where it was only 9.6, the average range of diurnal variation of the different magnetic elements was from 50 to 70 per cent greater in years of many than in years of few sun-spots.

Since the diurnal variation of magnetic elements is principally, if not wholly, due to earth currents, or to the resultant of earth and air currents, and since the variation is diurnal, its cause must lie in the rotation of the earth in the electric or magnetic field of the sun. It seems necessarily to follow that the greater diurnal variation at times of greater sun-spot frequency must be due to some change in either the electric or the magnetic field of the sun.

The fact that the change in the magnetic elements may be shown to be principally, if not wholly, due to electric currents, as well as the fact that the magnetic field of the sun is known to be vanishingly small at the distance of the earth, makes it seem that the solar change involved in the change of magnetic variation must be an electric change.

The first part of the preceding proposition assumes that there must be a difference in the diurnal range of earth-currents with a difference in sun-spot frequency, and while this fact seems to have hitherto been overlooked, it may be plainly seen in Weinstein's Berlin earth-current curves.*

There seem to be two possible kinds of change in the electric charge of the sun which may influence its electrostatic induction upon another body, viz., a change in the total charge of the sun, or a different distribution of that charge over the solar surface. A change in the total charge of the sun from year to year, especially an alternate increase and decrease of that charge every eleven years, seems highly improbable; a periodic change of distribution of that charge over the solar surface due to the induction of other charges upon it does not seem so improbable.

* *Die Erdströme im Deutschen Reichstelegraphengebiet.* Tafeln.

We know that the solar corona shows a very different outline at times of maximum and minimum sun-spot frequency. If the solar corona is an electron atmosphere, which seems to be the only possible explanation of it hitherto proposed, it must represent an important part of the sun's electrical charge. In that case, we have visible evidence of the different distribution of the solar charge at times of maximum and minimum sun-spot frequency. The inductive influence of this charge upon the earth's charge must likewise vary with the sun-spot frequency.

It is evident, also, that such a change in the distribution of the solar charge must cause a change in the magnetic field of the sun.

On the electron atmosphere of the earth.—In 1896 Adam Paulsen explained the various forms which the aurora may take by attributing them to an electric discharge through an ionized atmosphere in the earth's magnetic field. At the present time it seems to be the conclusion of most investigators who have tried to account for the bending of radio waves around the earth and for the "skip" phenomenon in the case of short radio waves that there is a highly ionized atmospheric layer at a height of from 50 to 80 kilometers in the daytime and from two to four times that high at night. It is also higher in the winter than in the summer. It has been estimated that the free electrons in this atmosphere must be as numerous as 10^5 or 10^6 to the cubic centimeter and may be more numerous.

Attempts to explain the origin of such an ionized atmosphere have failed. It has sometimes been assumed that it may be accounted for in the daytime by the photoelectric effect of sunlight; but an ionization due to ultra-violet light should rapidly disappear when the light is withdrawn, while the ionized layer of the atmosphere seems more definite by night than by day.

There is an increasing belief that the solar corona is due to an electron atmosphere above the gaseous atmosphere of the sun, and the high negative charge of the sun would seem to make the existence of such an atmosphere extremely probable. Since the earth also carries a very great negative charge, it may be expected to have an electron atmosphere overlying and penetrating into the gaseous atmosphere.

Such an atmosphere is subject to the electrical induction of the charges of the sun and the moon. If it is sufficiently mobile it will be denser and higher on the night side of the earth than on the day side, and on the winter hemisphere than on the summer hemisphere.

As the earth rotates from west to east, the electron atmosphere will move, *relative to the earth,* from east to west; that is, there will be an electric current set up in it in the same direction as the negative electric current in the earth. Since the atmospheric currents are above our magnetic needles while the earth-currents are below them, they will tend to

neutralize each other's effect upon the magnetic needle. The earth-currents are in a direction to weaken the earth's magnetic field. The currents in the upper atmosphere are in a direction to increase the magnetic field of the earth *between them and the surface of the earth.*

Most attempts at the analysis of that magnetic field of the earth which we measure, i.e., between the surface of the earth and the upper atmosphere, have led to the conclusion that a small part of this field is due to electric currents above the earth. The direction of flow of the electrons which would produce such a current must be opposite to the direction of rotation of the earth. An atmosphere of electrons would partake of the motion of the earth unless it were repelled by a negative charge on some other body. If the earth has an outer atmosphere of electron gas, the electrical induction of the sun's negative charge and the rotation of the earth will account for the external part of the earth's magnetic field.

The seasonal variation of the density and height of the electron atmosphere will be due to the change in the apparent declination of the sun. The *rate of change of density* will be a function of the rate of change of the solar declination. It will be greatest at the equinoxes and least at the solstices.

The earth's electron atmosphere and auroras.—Another phenomenon which has long been attributed to an electric discharge through an ionized region in the upper atmosphere is the aurora. As has already been said, the ionized upper atmosphere was first assumed by Paulsen to account for the phenomena of auroras. He says (translation by present writer):

> It is known that negative electricity may be dispersed by light rays of great refrangibility. It is then comprehensible that the solar radiation falling upon the negative electric masses in the higher atmosphere may drive these particles toward higher latitudes, so that in polar regions the electricity will acquire such a density that the strong emission of cathode rays may produce the intense northern lights.

The theory proposed here differs from Paulsen's mainly in assuming the electrostatic induction of the sun's negative charge, instead of a repulsion due to ultra-violet light, as the force which impels electrons in the upper atmosphere toward higher latitudes. It should be remembered that at the time of Paulsen's writing the electron had not been fully identified and the action of light upon it had not been investigated.

However, it is a fact that the intense northern lights do not occur in extreme polar regions. The region of maximum auroral frequency is an approximately circular zone surrounding the north pole and the northern magnetic pole, extending to latitudes below 60° in Labrador and to about 80° on the Asiatic side of the pole. From this region the auroral frequency falls off both toward the north and the south. North of this zone, as in Greenland and Iceland, auroras are most frequently seen to the southward.

There is likewise a difference in the periods of maximum frequency north and south of the principal auroral zone. On the north side their greatest frequency occurs at the time of the winter solstice, while south of this zone there are two maxima, occurring at the equinoxes, and two minima, occurring at the solstices, the principal minimum occurring at the summer solstice. This may be seen in Table VI, which is taken from Arrhenius' *Kosmische Physik*, p. 913.

TABLE VI

Annual Variation of Auroral Frequencies

Month	Northern Hemisphere	Iceland and Greenland	Southern Hemisphere	Change in Solar Declination
January	2212	804	56	5°.4
February	2959	734	126	9°.0
March	3043	613	183	11°.7
April	2382	128	148	10°.3
May	1446	1	54	7°.0
June	1071	0	40	1°.5
July	1277	0	35	4°.7
August	1419	40	75	9°.3
September	2999	455	120	11°.0
October	3097	716	192	11°.0
November	2643	811	112	7°.4
December	2112	863	81	1°.5

The foregoing data are shown graphically in curves given in Figure 9.

The variation in auroral frequency during the year cannot be due to electron discharge from the sun, as such discharge should not be affected by the inclination of the earth's axis with reference to the sun. Also, if auroras were due to discharges from the sun they should be most frequent in the Northern Hemisphere at the time of the summer solstice and least at the time of the winter solstice. This is the opposite of what occurs in Iceland and Greenland, which lie north of the zone of greatest frequency, and is not true for any known part of the earth. It is not true for southern auroras in so far as they are known.

On the other hand, if auroral discharges are due to the increase of density of electrons in the upper atmosphere caused by the elctrostatic repulsion of the sun, their greatest frequency in any region should occur when that region is turned from the sun. This is the case in the north polar region, while data from the region around the south pole seems to be lacking.

However, we have seen that the greatest auroral frequency is not at the pole, but is at a distance of from 15 to 35 degrees from it. This would seem to be due to the magnetic field of the earth. Electrons moving to the

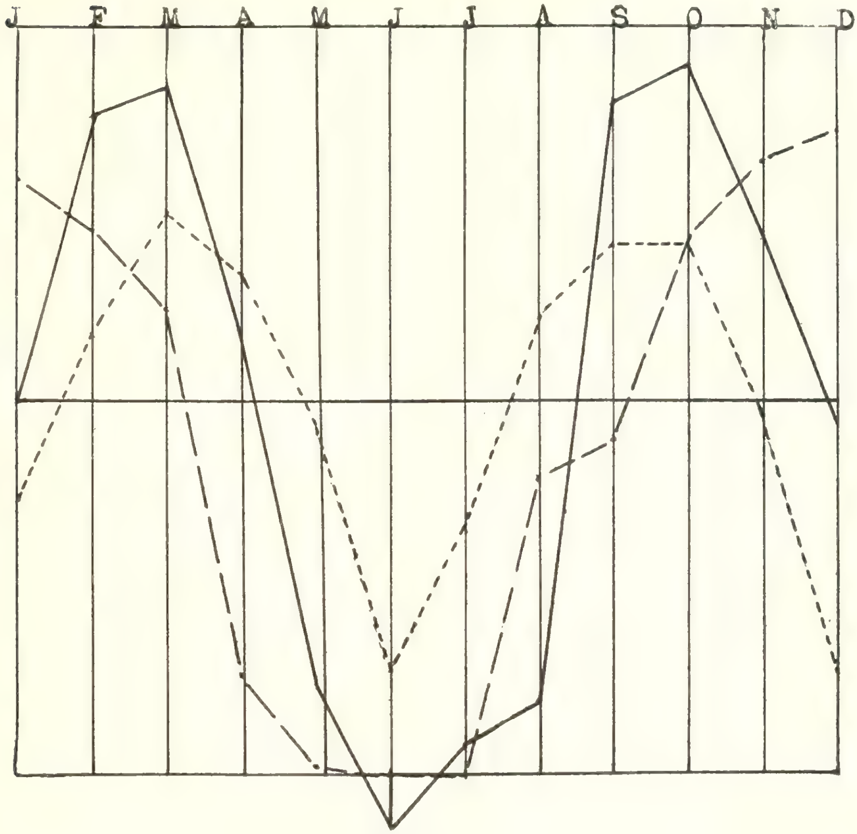

FIGURE 9

The continuous curve represents the monthly frequencies of auroras in Norway, Sweden, and the United States of America; the dashed curve, the monthly frequencies in Iceland and Greenland; and the short dashed curve, the change in solar declination during the given month.

north or south in middle latitudes are traveling approximately parallel to the magnetic force lines of the earth. As they approach the pole the magnetic force lines become more and more nearly perpendicular to the earth's surface and hence to the path of the migrating electrons. The electrons are retarded and also have their paths bent upward or downward along the force lines. Where the magnetic inclination reaches about 80 or 85 degrees the electron density becomes greatest and their accelerating force upon one another highest. It seems not unreasonable to suppose that some of them which have been driven upward along the force lines follow these lines backward toward the south and thus produce the great world-wide auroras.

In any case, since their paths will lie along the force lines, the luminous discharges due to their collisions with gaseous molecules or ions will be along these lines, and the observed orientation of the various forms of auroral discharge will be accounted for. It also seems significant that the lower limit of auroral rays (about 80 kilometers) seems to correspond so closely to the height of the reflecting layer for radio waves.

The spectrum of a star as an indicator of its electrical condition.—It seems to be a well-established fact that electrons may be separated from normal elementary atoms by means of suitable electrical fields, and that the atomic ions produced in this way are themselves capable of giving spectral series of the same general character as the spectra of normal atoms. It also seems plain that if such ions could be kept under suitable electrical conditions they would persist as elementary atoms.

It is well known that many stars and nebulae give spectra due to such persistent ions, which in this case must be normal gaseous atoms on the bodies where they are observed.

Lockyer regarded these "proto-elements" as the primordial elements which, due to a lowering of temperature, have coalesced or taken on new parts to form the chemical elements which are normal in our solar system; but this change may equally well have been brought about by a change in the electrical condition of our sun, or of the stars under consideration. Thus if our sun were once expanded to a circumference equal to the orbit of Neptune and has then condensed to its present size without changing its total electric charge (assuming it to have had an electric charge), the electric potential gradient over its surface is now more than thirty thousand times as great as it was then, or if all the bodies of the solar system are now equally charged, their electrical potential is about five thousand times as great as it was then.

We now know that Lockyer's proto-elements may be produced electrically, but the question whether they may be produced by an increase of temperature seems incapable of experimental determination. The fact that enhanced lines exist in the spectra of nebulae is an argument against their dependence upon high temperatures. If we regard their appearance in the spectrum of a star as an indication of the electrical condition of that star, rather than of its temperature, we may yet be able to calculate the electrical state of some of the stars.

The expense of publication of this volume is borne by a fund contributed by the author's former students